Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the South Bay Ocean Outfall (SBOO) to assist in evaluating possible impacts of the outfall on the marine environment. Treated wastewater is currently discharged to the Pacific Ocean via the SBOO at a depth of ~27 m and at a distance of approximately 5.6 km west of Imperial Beach. During 2007, average daily flow through the outfall was 25 mgd. Changes in current patterns, water temperatures, salinity, and density can affect the fate of the wastewater plume. These types of changes can also affect the distribution of turbidity (or contaminant) plumes that originate from various non-point sources. In the South Bay region these include tidal exchange from San Diego Bay, storm water discharge, surface water runoff from local watersheds, and outflows from the Tijuana River and Los Buenos Creek (Mexico). For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sedimentation, and bacterial contamination (see Largier et al. 2004). These factors can affect water quality within the region either individually or synergistically.

The fate of SBOO wastewater discharged into offshore waters is determined by oceanographic conditions and other events that impact horizontal and vertical mixing. Consequently, physical and chemical parameters that determine water column mixing potential, such as water temperature, salinity, and density are important components of ocean monitoring programs (Bowden 1975). Analysis of the spatial and temporal variability of these parameters in addition to transmissivity, dissolved oxygen, pH, and chlorophyll can elucidate patterns of water mass movement. Analysis of all of these parameters together for the receiving waters surrounding the SBOO can help (1) describe deviations from expected patterns, (2) assess the impact of the wastewater plume relative to other input sources, (3) determine the extent to which water mass movement or mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations.

Remote sensing observations from aerial and satellite imagery, and evaluation of bacterial distribution patterns may provide the best indication of the horizontal transport of discharge waters in the absence of information on deepwater currents (Pickard and Emory 1990; Svejkovsky 2006, 2007a, b; also see Chapter 3 of this report). Thus, the City of San Diego combines measurements of physical oceanographic parameters with assessments of indicator bacteria concentrations and remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site.

This chapter describes the oceanographic conditions that occurred in the South Bay region during 2007, and is referred to in subsequent chapters to explain patterns of bacteriological occurrence (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Field Sampling

Oceanographic measurements were collected at least once per month at 40 fixed monitoring stations (**Figure 2.1**). These stations are located between 3.4–14.6 km offshore along the 9, 19, 28, 38, 55 and 60-m depth contours, and form a grid encompassing an area of ~450 km^2 surrounding the outfall. Three of these stations (I25, I26, I39) are considered kelp bed stations and are subject to the 2001 California Ocean Plan water contact standards (see Chapter 3);

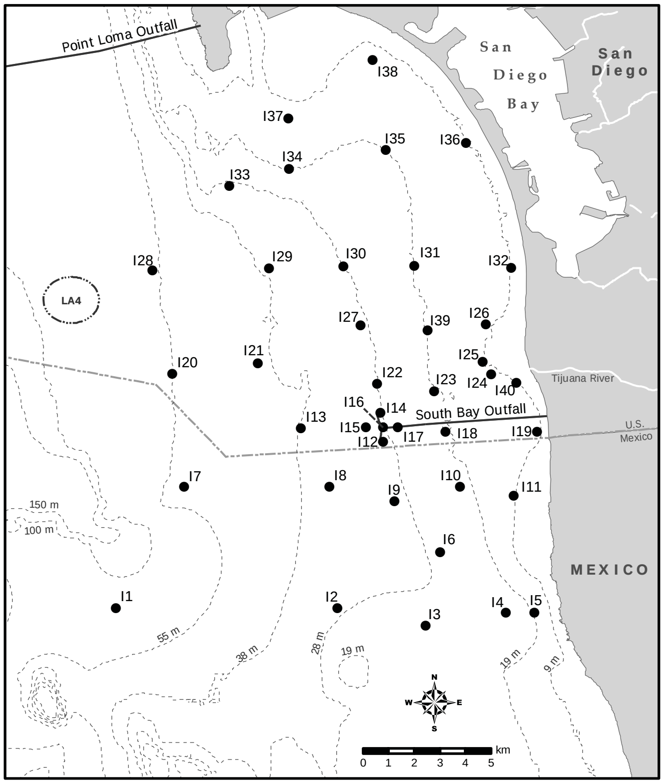

Figure 2.1
Water quality monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

each of these stations was sampled an additional four times per month.

Data for various water column parameters were collected using a SeaBird conductivity, temperature, and depth (CTD) instrument. The CTD was lowered through the water column at each station to collect continuous measurements of water temperature (°C), salinity (parts per thousand = ppt), density (δ/θ), pH, water clarity (% transmissivity), chlorophyll *a* (µg/L), and dissolved oxygen (mg/L). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This ensured that physical measurements used in subsequent data analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Monitoring of the SBOO monitoring area also included aerial and satellite imagery generated and analyzed by Ocean Imaging (OI) of Solana Beach, CA (see Svejkovsky 2008). All usable images captured during 2007 by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded, and several quality Landsat Thematic Mapper (TM) images were purchased. High resolution aerial images were collected with OI's DMSC-MKII digital multispectral sensor (DMSC). Its four channels were configured to a specific wavelength (color) combination which maximizes the detection of the SBOO wastewater plume's turbidity signature by differentiating between the plume and coastal turbidity. The depth penetration of the sensor varies between 8–15 m, depending on overall water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 m. Fifteen overflights were conducted in 2007, which consisted of two overflights per month during the winter when the outfall plume had the greatest surfacing potential, and one overflight per month during spring and summer.

Data Treatment

The water column parameters measured in 2007 were summarized for each month by depth zone; profile data from the three kelp stations were summarized for surface depths (≤2 m) and bottom depths (10–20 m), whereas profile data from the other offshore stations were summarized for surface depths (≤2 m), mid-depths (10–20 m), and bottom depths (≥ 27 m).

Mean temperature and salinity profile data from 2007 were compared with profile plots for 1995–2006 that consisted of means ±1 standard deviation (SD) at 5-m depth increments. Data for these comparisons were limited to four stations located along the 28-m depth contour, including station I12 located near the end of the southern diffuser leg, station I9 located south of the outfall, and stations I22 and I27 located north of the outfall. In addition, a time series of anomalies for each water column parameter was created to evaluate significant oceanographic events in the SBOO region.

Anomalies were calculated by subtracting the monthly means for each year (1995–2007) from the mean of all 13 years combined. Means were calculated using the same four stations described above, all depths combined.

Results and Discussion

Climate Factors and Ocean Conditions

Southern California weather can generally be classified into wet (winter) and dry (spring–fall) seasons (NOAA/NWS 2008a), and differences between these seasons affect certain oceanographic conditions (e.g., water column stratification, current patterns and direction). Understanding patterns of change in such conditions is important in that they can affect the transport and distribution of wastewater, storm water, or other types of turbidity plumes that may arise from various point or non-point sources (e.g., ocean outfalls, storm drains, outflows from rivers and bays, surface runoff from coastal watersheds). Winter conditions typically prevail in southern California from December through February during which time higher wind, rain and wave activity often contribute to the formation of a well-mixed or relatively homogenous (non-stratified) water column. The chance that the wastewater plume from the SBOO may surface is highest during such times when there is little, if any, stratification of the water column. These conditions often extend into March as the frequency of winter storms decreases and the seasons begin to transition from wet to dry. In late March or April the increasing elevation of the sun and lengthening days begin to warm surface waters, mixing conditions diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In October or November, cooler temperatures associated with seasonal changes in isotherms, reduced solar input, along with increases in stormy weather, begin to cause the return of well-mixed or non-stratified water column conditions.

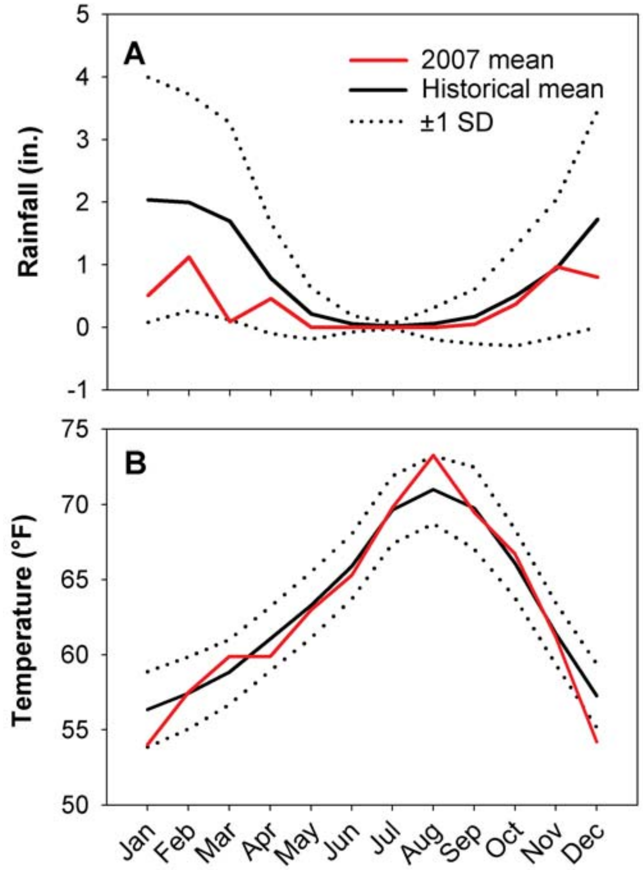

Figure 2.2
Total monthly rainfall (A) and monthly mean air temperature (B) at Lindbergh Field (San Diego, CA) for 2007 compared to monthly mean rainfall and air temperature (±1 SD) for the historical period 1914–2006.

Total rainfall was only a little over 4 inches in the San Diego region during 2007, which was well below the historical average of more than 10 inches/year (NOAA/NWS 2008b). Although below normal, rainfall followed expected seasonal patterns, with the greatest and most frequent rains occurring during February (**Figure 2.2A**). In contrast, air temperatures were generally similar during the year to historical averages, although exceptions occurred in January, August and December (Figure 2.2B). The above normal air temperatures present during the summer months coincided with higher than normal surface water temperatures and salinity values that were observed in the SBOO region (see below). Aerial imagery indicated that current flow was predominantly southward in 2007, although with occasional northward flows occurred following storm events (Svejkovsky 2008). For example, increased outflows from the Tijuana

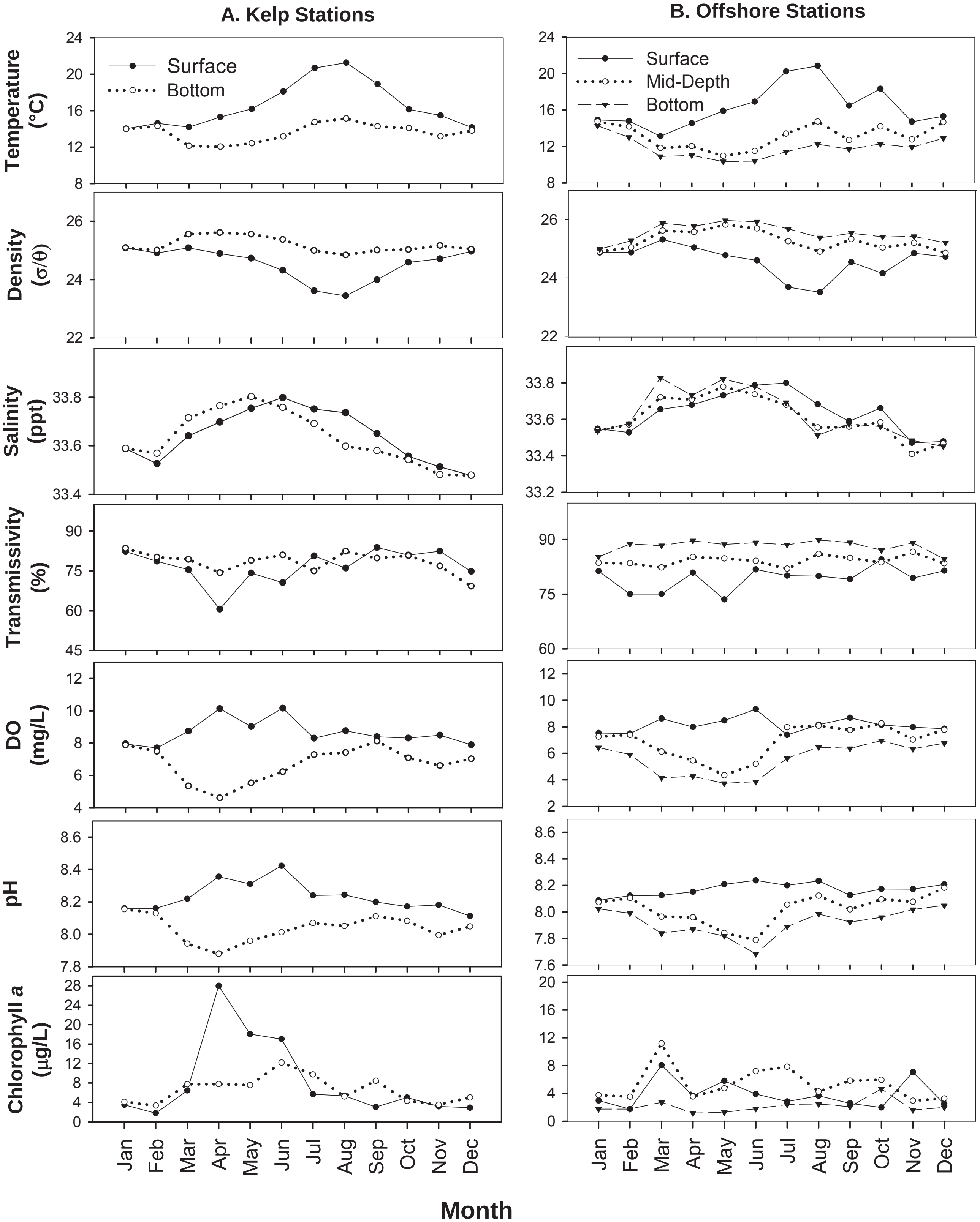

Figure 2.3

Monthly mean temperature, density, salinity, transmissivity, dissolved oxygen (DO), pH, and chlorophyll *a* values for (A) surface (≤2m) and bottom (10-20 m) waters at the kelp stations and (B) surface (≤2m), mid-depth (10–20 m) and bottom (≥27m) waters at SBOO stations during 2007.

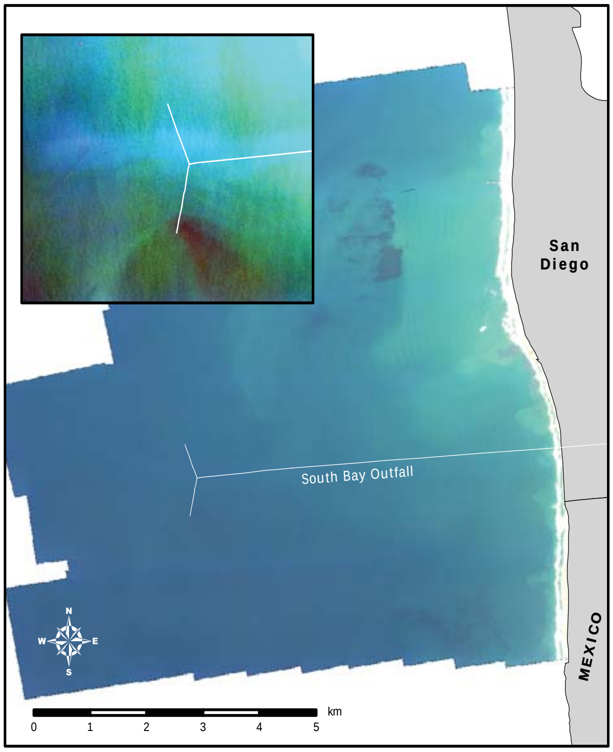

Figure 2.4
DMSC image composite of the SBOO outfall and coastal region acquired on January 3, 2007. Effluent from the south diffuser leg is seen as red plume in the inset and indicates a southerly flow.

River and Los Buenos Creek during the wet season resulted in large northward-flowing turbidity plumes along the coast. These plumes were often associated with increases in bacterial contamination along the shoreline or in nearshore waters (see Chapter 3).

Oceanographic Conditions in 2007

Water Temperature

Water temperature is the main factor affecting water density and stratification of southern California ocean waters (Dailey et al. 1993, Largier et al. 2004), and differences in surface and bottom temperatures can provide the best indication of the surfacing potential of wastewater plumes This is particularly true for the South Bay outfall region where waters are relatively shallow and salinity is relatively constant. In 2007, surface temperatures at the kelp stations ranged from 14.0°C in January to 21.3°C in August, whereas bottom temperatures ranged from 12.0°C in April to 15.1°C in August (**Appendix A.1**). Temperatures at the other offshore stations ranged from 13.1°C in March to 20.9°C in August in surface waters, and from 10.4°C in May/June to 14.3°C in January in bottom waters (**Appendix A.2**). Thermal stratification of the water column generally followed normal seasonal patterns, with the least stratification occurring during the winter (January–March, December), and the greatest stratification occurred during July and August in the summer (**Figure 2.3**).

Remote sensing results generally confirmed water column stratification patterns that were apparent in CTD data (Svejkovsky 2008). For example, DMSC aerial imagery detected the near-surface signature of the wastewater plume on several occasions above the location of the SBOO southern terminus when the water column was well mixed (i.e., not stratified). This included the period from January–March (see **Figure 2.4**), and during November and December. Subsequent aerial imagery suggested that the plume, as usual, remained deeply submerged from June–October when the water column was stratified.

Salinity

Salinity profiles were relatively uniform in 2007. Salinities at the kelp stations ranged from 33.48 ppt in December to 33.80 ppt in June in surface waters, and from 33.48 ppt in November and December to 33.80 ppt in May at bottom depths (Appendix A.1). Surface salinities at the other offshore stations ranged from 33.47 ppt in November to 33.80 ppt in July, while bottom salinities ranged from 33.45 ppt in December to 33.83 ppt in March (Appendix A.2). Salinity values at all stations followed normal seasonal patterns with values increasing at all depths from March through July, followed by a steady decline thereafter (Figure 2.3).

Density

Density, a product of temperature, salinity, and pressure, is influenced primarily by temperature differences in the South Bay region where depths are shallow and salinity profiles are relatively uniform. Therefore, changes in density typically mirror changes in water temperature. This relationship was true for 2007, as indicated by water column data collected at the kelp and other offshore water quality stations (Appendix A.1, A.2). The differences between surface and bottom water densities resulted in a pycnocline from April through October with maximum stratification occurring in August (Figure 2.3).

Chlorophyll *a*

Mean chlorophyll *a* concentrations in surface waters ranged from 1.8 µg/L in February to 28.0 µg/L in April at the kelp stations, and from 1.7 µg/L in February to 8.1 µg/L in March at the other offshore stations (Appendix A.1, A.2). The high chlorophyll values reported for surface waters beginning in March corresponded to plankton blooms observed in MODIS satellite imagery (Svejkovsky 2008). The spring plankton blooms are likely the result of upwelling events that typically occur during this time of the year (Jackson 1986, Svejkovsky 2008). Elevated chlorophyll concentrations persisted at the kelp stations from March until June, but declined gradually from 28.0 µg/L to 17.0 µg/L. Chlorophyll levels were also elevated at offshore mid-depths and kelp station bottom depths during June, July and September, which was most likely due to decaying plankton sinking towards the bottom. Increases in plankton density, as estimated using chlorophyll *a*, likely influenced some of the declines in transmissivity and increases in dissolved oxygen and pH that occurred during these periods (Figure 2.3).

Historical Assessment of Oceanographic Conditions

Water temperatures at stations I9, I12, I22, and I27 exceeded historical ranges during most of 2007 (**Figure 2.5**). Average temperatures for March–June and September–November of 2007 were much lower than the historical average due to strong upwelling that occurred during the year. In contrast, temperatures in the upper 15 m of the water column during August were well above the historical average. The relatively high temperatures recorded in surface waters in August may have been influenced by the above average air temperatures for this month (NOAA/NWS 2008b).

Salinity values were also well above historical averages (**Figure 2.6**), another indication that stronger than normal upwelling may have occurred during these periods. Previous studies of the South Bay region have concluded that topographic features such as the Point Loma headland create a divergence of the prevailing southerly flow as it encounters shallower isobaths, creating a vorticity that transports deeper water to the surface (i.e., upwelling) where it is subsequently swept southward within the South Bay (see **Figure 2.7**; Roughan et al. 2005; City of San Diego 2007). This is supported by MODIS imagery and CODAR plots, which indicated the presence of strong southward currents during March, April, September, October and November of 2007 (Svejkovsky 2008). Furthermore, large plankton and turbidity plumes were observed moving offshore and across South Bay during these months. In addition, maximum wind speed for 2007 occurred in March (32 mph NW) and may have contributed to the upwelling event in early spring (Appendix A.3).

A review of oceanographic data between 1995 and 2007, using the same four SBOO stations (I9, I12, I22, I27), does not reveal any measurable impact that can be attributed to the beginning of wastewater discharge via the SBOO in 1999 (**Figure 2.8**). Instead, these data are notably consistent with changes in large scale patterns observed for the region by CalCOFI (Peterson et al. 2006; Goericke et al. 2007). Four significant events have affected the California Current System (CCS) during the last decade: (1) the 1997–1998 El Niño event; (2) a dramatic shift to cold ocean conditions that lasted from 1999 through 2002; (3) a more subtle but persistent return to warm ocean conditions beginning in October 2002; (4) the intrusion of subarctic surface waters that resulted in lower than normal salinities in southern California during 2002–2003. Temperature and salinity data for the South Bay region are consistent with the first, second,

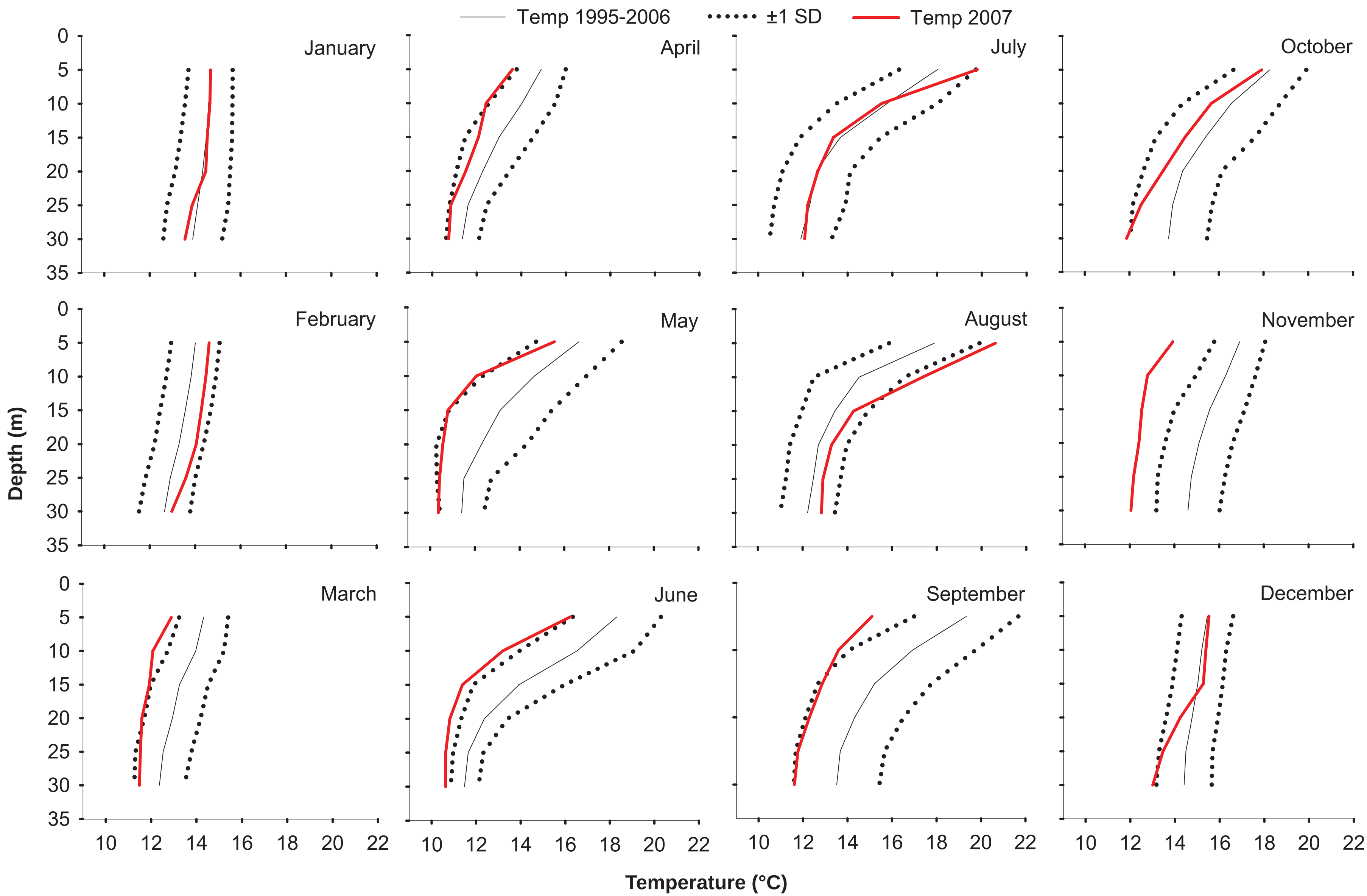

Figure 2.5
Mean temperature CTD profile data for January–December 2007 compared to mean temperature (±1 SD) profiles for the historical period 1995 through 2006 at stations I9, I12, I22, and I27.

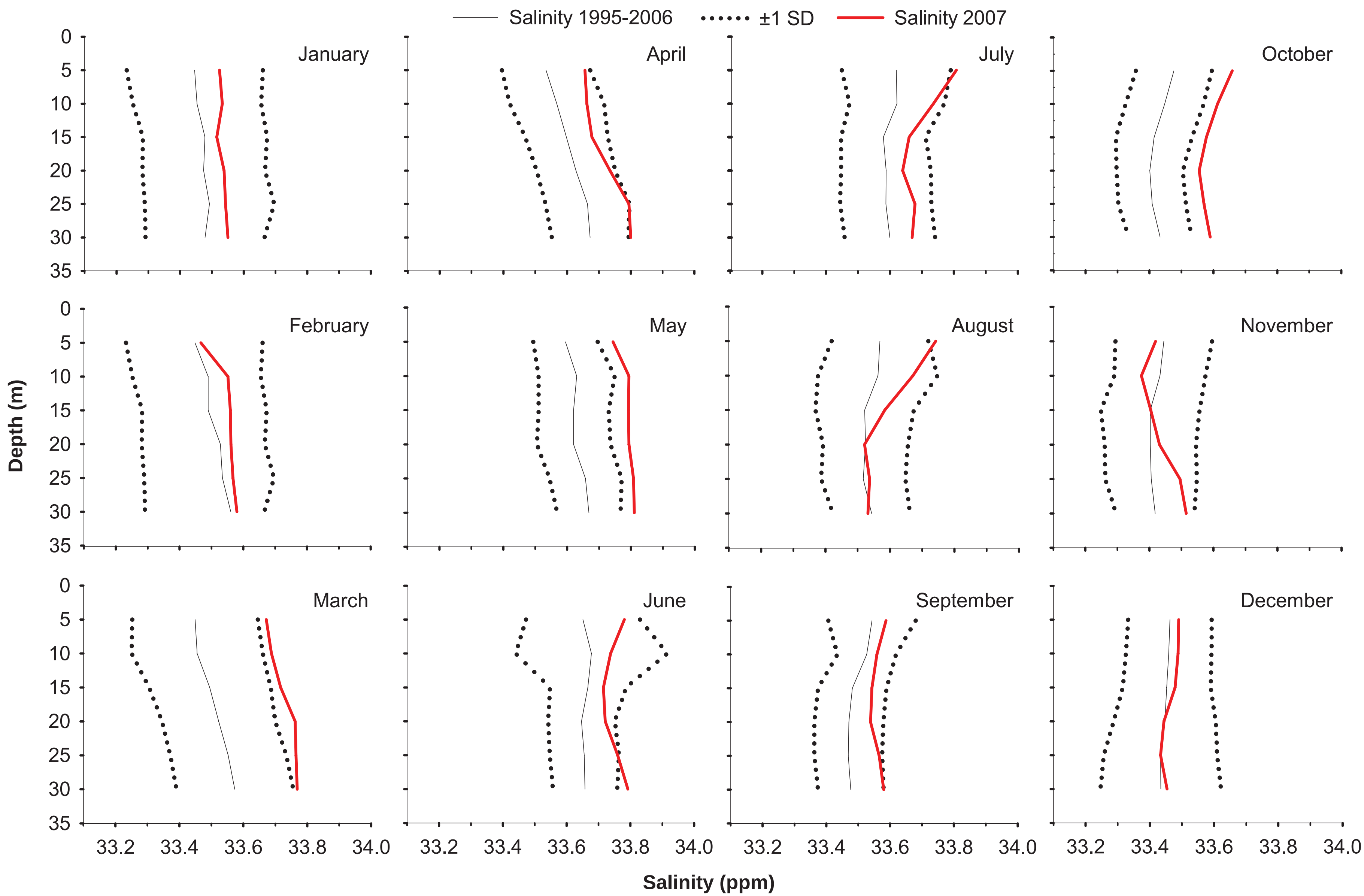

Figure 2.6
Mean salinity CTD profile data for January–December 2007 compared to mean salinity (±1 SD) profiles for the historical period 1995 through 2006 at stations I9, I12, I22, and I27.

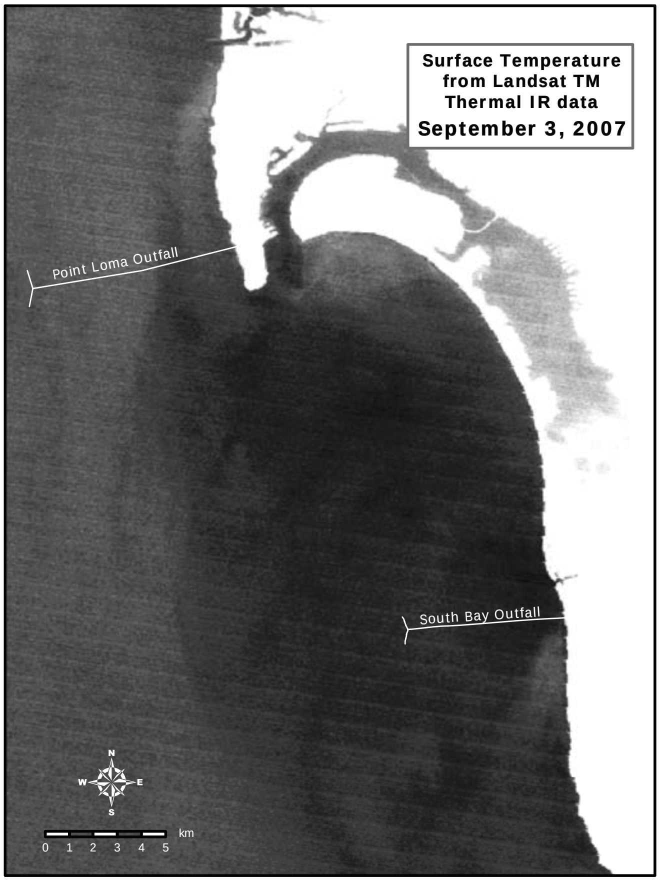

Figure 2.7
TM infrared satellite imagery from September 3, 2007 showing the San Diego water quality monitoring region. Cooler water resulting from upwelling events appears as darker shades of gray.

and fourth CCS events. However, the trend of cooler water beginning in 2005 and continuing through 2007 (Figure 2.8) varies from other surveys of the California Current System and is more consistent with data from northern Baja California (Mexico) where water temperatures were below the decadal mean during 2005 and 2006 (Peterson et al. 2006).

Salinity values within the South Bay region were higher than the historical average (i.e., above “normal”) during most of 2007 (Figure 2.8), with the largest deviations occurring in March and October. These results provide further evidence of upwelling events that occurred during these months.

Overall water clarity (transmissivity) has generally increased in the South Bay region since initiation of discharge in 1999, despite several intermittent periods when clarity was below normal (Figure 2.8). Transmissivity was much lower than normal during the winter months of several years (e.g., 1998, 2000); these periods of low transmissivity are likely due to increased suspension of sediments caused by strong storm activity (see NOAA/NWS 2008b). In addition, below average water clarity events that occur in spring and early summer months are probably related to plankton blooms such as those observed throughout the region in 2005 (City of San Diego 2006). In contrast, water clarity during 2006 and 2007 was mostly above the historical average; these results are indicative of reduced turbidity due to the lack of storm activity and rainfall that totaled less than 11 inches for these two years.

Chlorophyll *a* concentrations in the South Bay region have been below average more often than not since measurements began in 1998 (Figure 2.8). These results are consistent with those observed in northern Baja California, and are in contrast to the rest of southern California during recent years (Peterson et al. 2006). Occasional periods of higher than normal chlorophyll concentrations within the South Bay region occurred as a result of red tides caused by the dinoflagellate *Lingulodinium polyedra*. This species persists in river mouths and responds with rapid population increases to optimal environmental conditions, such as significant amounts of nutrients from river runoff during rainy seasons (Gregorio and Pieper 2000). During 2007, chlorophyll levels were generally below the historical mean, with the exception of a few spikes that correspond with plankton blooms in March, April, June, and October.

There were no apparent trends in pH values or dissolved oxygen concentration related to the SBOO (Figure 2.8). These parameters are complex, dependent on water temperature and depth, and sensitive to physicochemical and biological processes (Skirrow 1975). Moreover, dissolved oxygen and pH are subject to diurnal and seasonal variations that make temporal

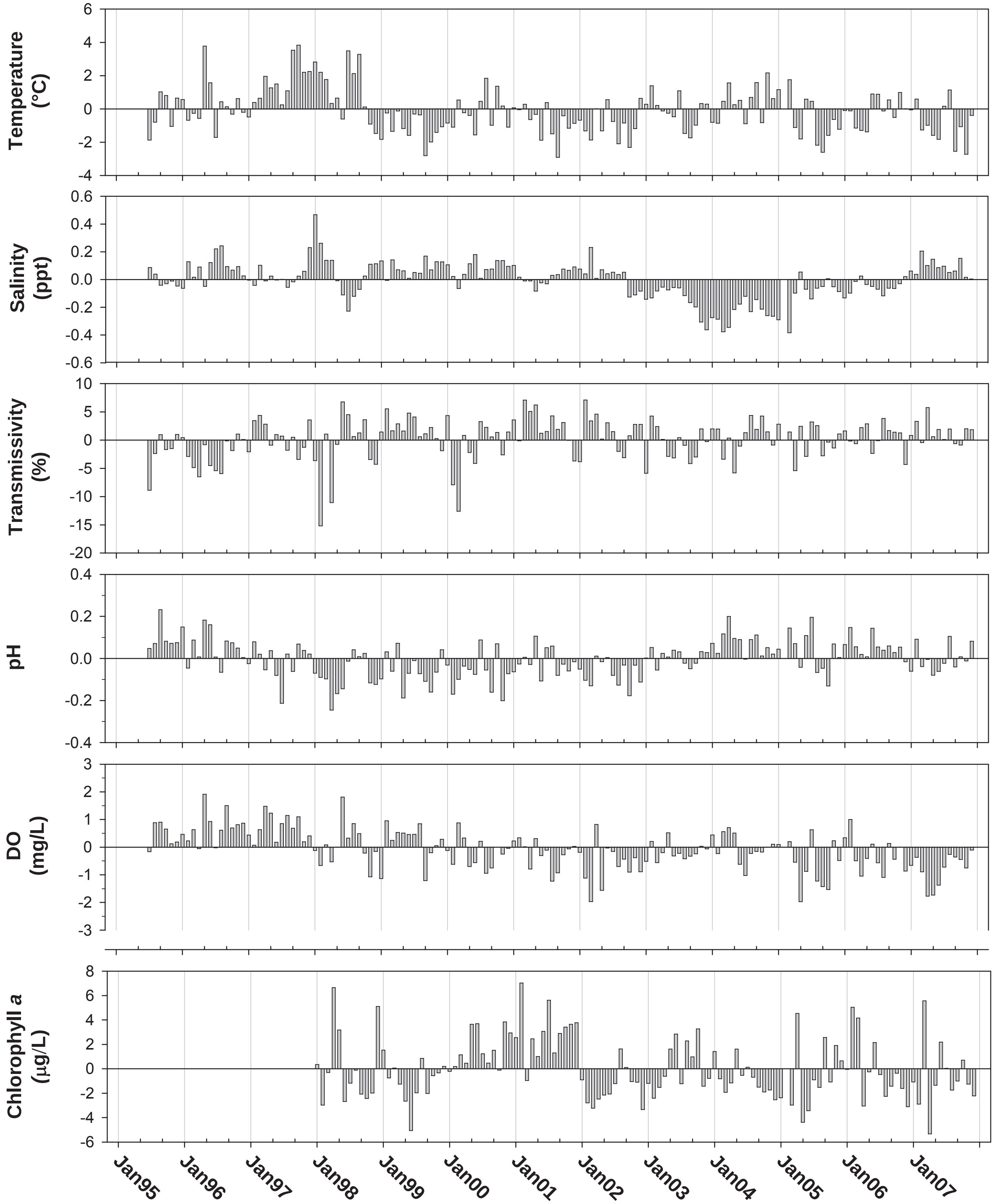

Figure 2.8

Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll *a* anomalies between 1995 and 2007. Anomalies were calculated by subtracting the monthly means for each year (1995–2007) from the mean of all 13 years combined; data were limited to stations I9, I12, I22, and I27, all depths combined.

changes difficult to evaluate. However, below normal concentrations of dissolved oxygen during 2005–2007 appear to be related to low levels of chlorophyll *a* during these years.

Summary and Conclusions

Oceanographic conditions in 2007 were characterized by strong upwelling and corresponding plankton blooms in the spring and fall and relatively high surface seawater temperatures in August. Upwelling events were indicated by cooler than normal water temperatures, especially at bottom depths, and higher than normal salinity during March–June and September–November. Plankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations (i.e., aerial and satellite imagery). The relatively high temperatures recorded in surface waters in August may have been influenced by the above average air temperatures that occurred during this month (see NOAA/NWS 2008b).

Thermal stratification of the water column followed typical patterns for the San Diego region with maximum stratification occurring in mid-summer and reduced stratification during the winter. DMSC aerial imagery detected the near-surface signature of the wastewater plume on several occasions between January through March and between November and December above the location of the SBOO southern terminus when the water column was well mixed. In contrast, the plume remained deeply submerged between June and October when the water column was stratified. Results from SBOO microbiology surveys further support that the plume remained offshore and submerged during these months (see Chapter 3).

Long-term analysis of water column data collected between 1995–2007 did not reveal any changes in oceanographic parameters that could be attributed to the discharge of wastewater that began in 1999. Instead, major changes in water temperatures and salinity for the South Bay region corresponded to significant climate events that occurred within the California Current System between 1995 and 2005 (see previous discussion). During late 2006 and early 2007, no clear patterns were observed in the California Current System, and regional or local processes dominated observed patterns. Additionally, water clarity has increased in the SBOO region since initiation of wastewater discharge, chlorophyll *a* levels in the area have remained consistent with water conditions in northern Baja California and changes in pH and dissolved oxygen levels have not exhibited any apparent trends related to wastewater discharge.

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